The Eddy Avenue Underbridge

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Reinforced concrete as a building material is so common in the Twenty First Century that it is hard to imagine that there was a time when it was not so widely used. The concept that the Romans used cement and concrete thousands of years ago might suggest that the technology is ancient, but with an emphasis on the *reinforced*, the material is quite modern, little more than a hundred years old.

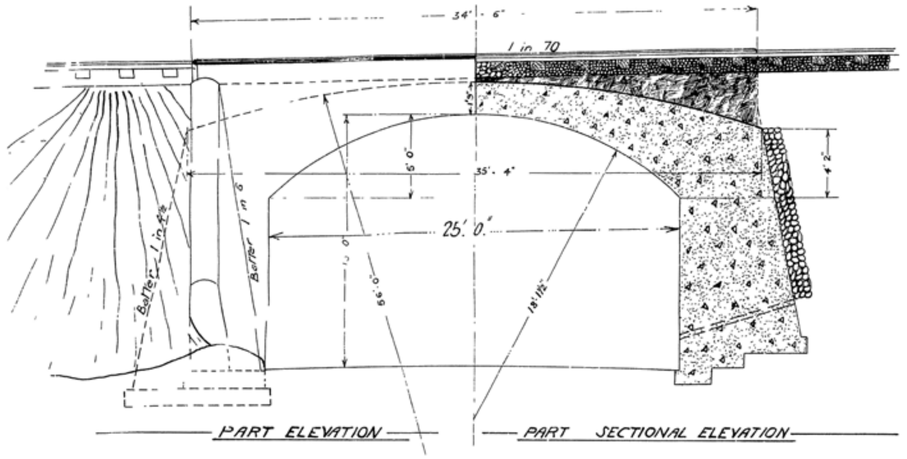
To understand the importance of the adjective – *reinforced* – we must look at the basic properties of concrete. Concrete is really little more than a very convenient form of stone, particularly useful because it is delivered to the structure as a liquid and thus readily takes up the shape of whatever formwork has been provided. Most of the bulk of concrete is crushed stone and the cement which is the active setting agent is manufactured from stone by intense heating.

Concrete is very hard to crush – it is strong in compression – but it is very weak in tension. These properties are very similar to those of stone and brick, and builders for centuries have been able to use stone for large span bridges by the simple expedient of ensuring, by the geometric design of the structure, that at no point in the bridge under any load conditions, could any part of the masonry come into tension. They built arches. Arches may be built from unattached wedge shaped blocks (called voussoirs) which have absolutely no connection or adhesion to each other. This is not just a principle which applies to old stone bridges. Gladesville road bridge, completed in 1964, is a series of discrete blocks completely unconnected to each other. There is a thin layer of concrete between the voussoirs to ensure that the blocks fit snugly to each other but this does not connect them.

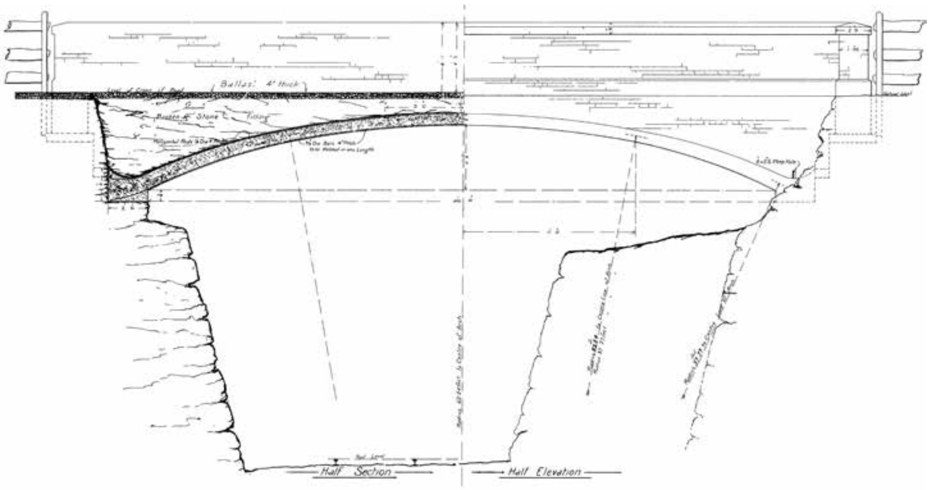
What all simple arch bridges rely on is geometry and the calculations by the engineers who designed them that the line of action of the compression force which clearly exists between the wedge shaped stones or concrete blocks always remains within the blocks. Once the line of the force is outside the blocks, the joints open and the bridge falls down. This works well for taller arches, but as the arch gets flatter, the forces get larger, and the difficulty of keeping the line of the force within the section, under all load conditions, increases. One answer for flat arches is to position some steel rods in the places where the blocks of masonry might go into tension and crack apart. That is not really practical for stone, but for liquid concrete it is very easy.

The first arch bridge built on this principle on the NSW Railways was a very flat overbridge at Hilltop, on the 1897 deviation of the original Main Southern line. It was put there in 1899[1], just after the line opened. Both faces of the thin arch ring have a grid of bars to save the concrete from cracking and the bridge falling.

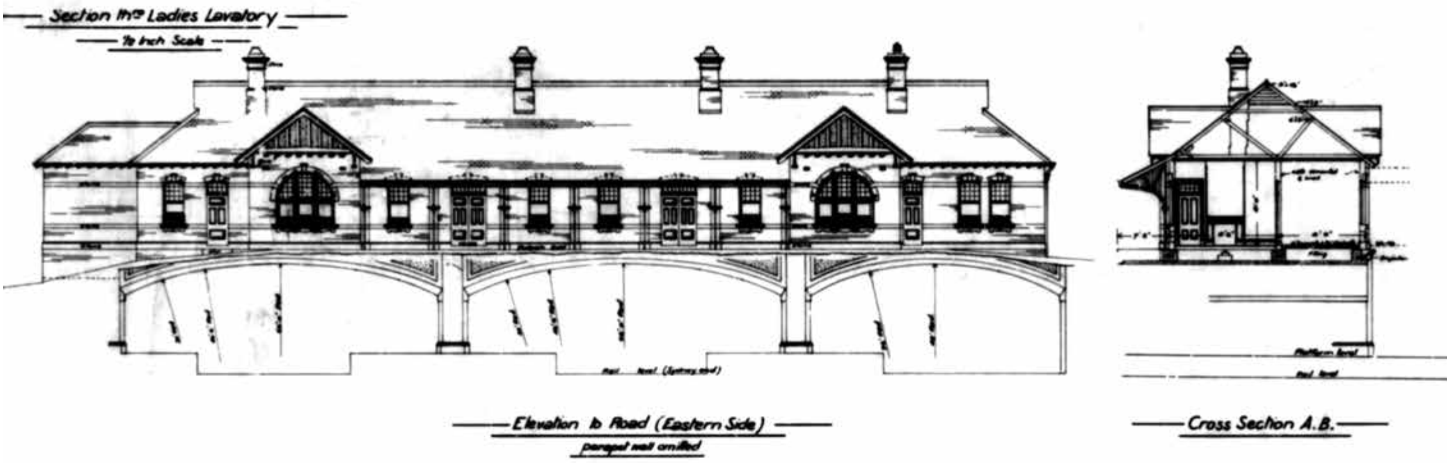
In those times reinforced concrete was known as Monier Concrete after Joseph Monier, an originally illiterate



ABOVE: Concrete was used for bridges before the concept of reinforcing was developed. This mass concrete arch was built in 1895 as part of the Locksley deviation. There is no steel embedded in the concrete. The bridge still carries the Main Western Line. ARHSnsw RRC 0125297



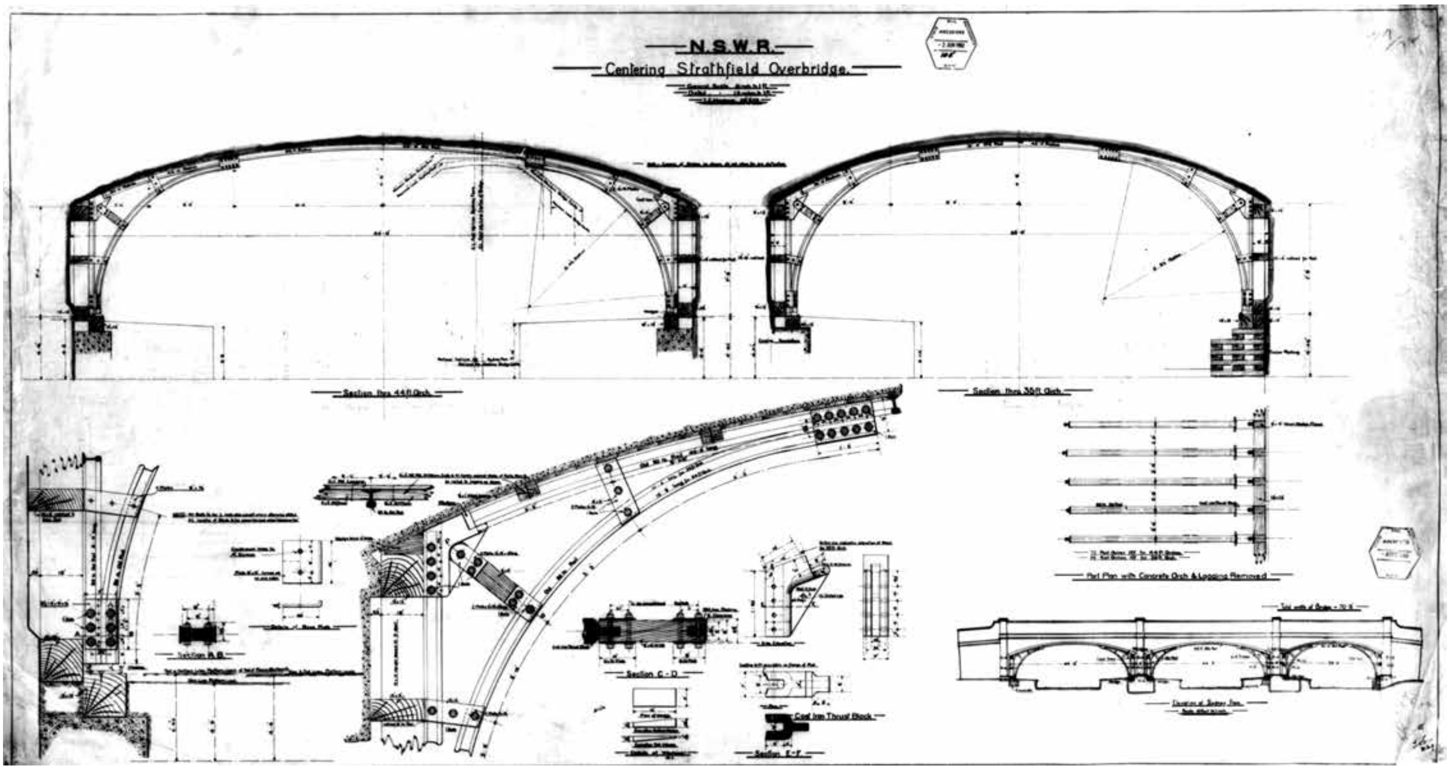
BELOW: The very flat and thin arch is reinforced with two layers of steel bars, though these are only 10 and 6mm in diameter. The notes specify that the long bars be welded (mechanically) into a single length. The concept of overlapping but unattached bars, embedded in the concrete, making as good a joint as a direct connection was as yet unrealised. ARHSnsw RRC

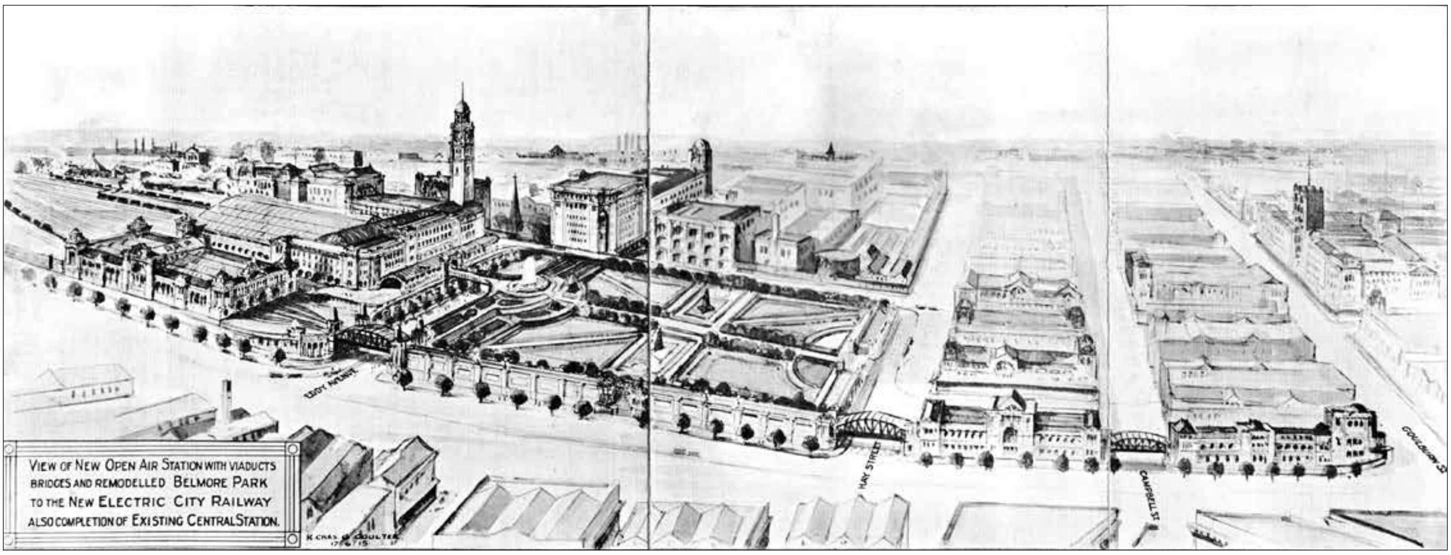


ABOVE: With three long spans, less than rigid abutments and a superimposed enormous and heavy station building, Strathfield was a giant, but perhaps foolhardy step. It had a short life. SRA APERTURE CARD COLLECTION.

BELOW: The bridge quickly became a matter of public concern and in 1909 this permanent steel centring was designed to support the arch. SRA APERTURE CARD COLLECTION.

BOTTOM: An illustration from Bradfield's 1915 report. Eddy Avenue Bridge, on the left, could never have been so short, or narrow. RRC COLLECTION





French gardener who had developed the idea as a means of making flower pots, and who in fact held a patent over it. He licensed the concept to Frank Gummow for the whole of Australia. Gummow, with his design engineer William Baltzer, built the first reinforced concrete bridges – sewerage aqueducts across Whites Creek and Johnstons Creek in Sydney, in 1897/98. Frank Gummow sub-let the rights to use the technique in Victoria and South Australia to John Monash. Monash was a prominent civil engineer in Victoria, who also had a part time interest in military affairs. During World War I he rose to command all the Australian troops, and others, in France, and became renowned for his achievements in that field, but at home every reinforced concrete structure owes something to him. When, in 1924, Sydney University sought referees for Bradfield's doctoral thesis, Monash[2] was one of those to whom they turned.

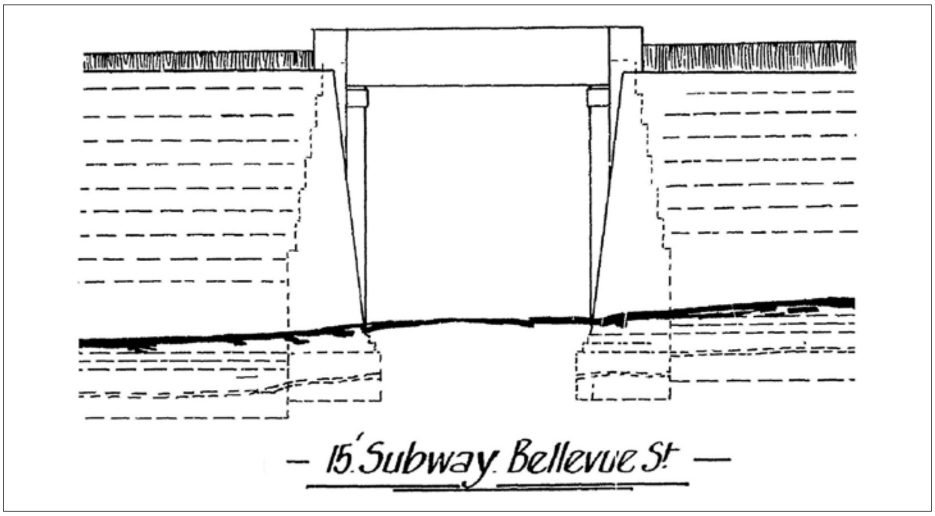
Hilltop may have been chosen as an out of the way place to test the new idea. It was also an ideal location with the bridge spanning between two very solid stone walls, and it was 'only' an overbridge – it did not carry the weight of the trains. The bridge still stands, apparently in perfect condition, and still carries traffic without any weight restriction.

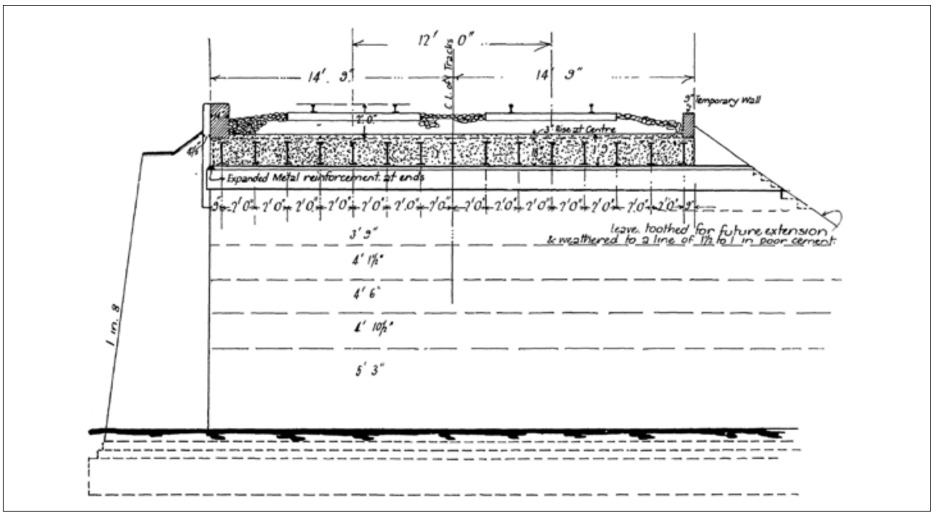
The railways engineers' next use of the Monier technique may have been a bit too ambitious. The Main Suburban Line needed a road crossing at Strathfield and this was placed over the station, which was in its present location. With the obvious crossing point as an underpass a little further west it is hard for those familiar with the present arrangement to imagine a bridge over the station, but it was built in 1899 as a three span Monier arch. The spans each covered two tracks, and the platforms as well, and the abutments, so absolutely crucial to the stability of a flat arch bridge, were built-up retaining walls and embankments. If that was not enough of a challenge, a heavy brick station building was provided on the bridge. It was still an overbridge, and did not perform very well. There was public debate in the press and in both Strathfield and Burwood Councils[3] calling for its repair[4] and a steel structure was designed to go underneath the arches to help keep them up. The whole station was redeveloped in 1927 with the crossing

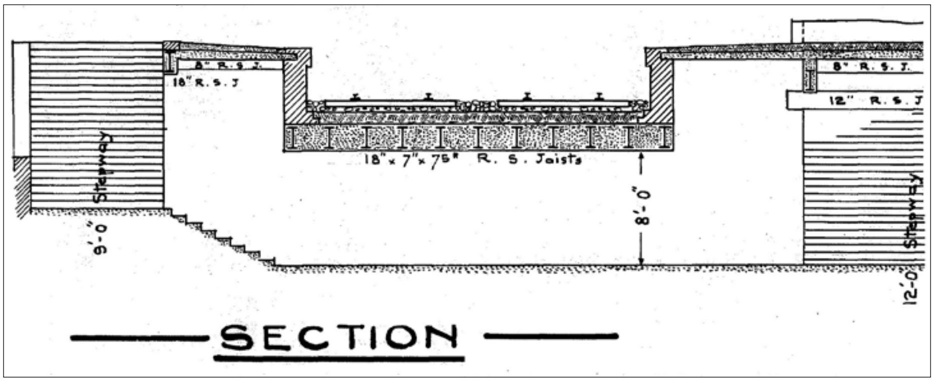
ABOVE: Concreting Hay Street arch. There are two batching plants on the approaches and these serve, by gravity, the lower parts of the arch. A third mixer at street level fills barrows which are being lifted from that place individually by crane. The tarp prevents spillages onto the sandstone façade. ARHSNSWRRC 518123

BELOW: At 15 feet (4.5m) span Bellevue Street is a minor bridge by any standard. RRC COLLECTION

BOTTOM: If Bellevue Street was built according to the surviving plans, and no others are known to exist, then it is very much a steel bridge, perhaps relying on concrete for corrosion protection. RRC COLLECTION







ABOVE: Banksia subway is clearly a steel bridge with closely spaced and large joists under the tracks. RRC Collection

BELOW: Central Northern Electric Concourse under construction. The identification of this work as a bridge carrying the tracks above is clear as well as the massive proportions of the grid of reinforced concrete beams required. ARHSnswRRC 517329

BOTTOM: The roof structure of Central Northern Concourse. Reinforcement is difficult to photograph, but this image, silhouetted against the sky is excellent. The 1924 use of plain round bars emphasises that this is 'reinforced concrete' in every modern sense of that term. Although the work is incomplete, the large number of bars in the bottom tension zone and their absence in the upper compression zone well illustrates the concept of the material. ARHSnswRRC 517293

moving west to its present location as an underpass and all trace of the bridge disappeared.

By the middle of the second decade of the new century work was underway on the major deviation of the Southern Line between Picton and Mittagong, and the almost universal design for the many bridges was the masonry arch. The several overbridges are typically concrete arches of a high rise. Most seem to be reinforced with curved scrap rails, though the plan for the bridge at Yanderra shows the rails as 'not being required'. All of the underbridges, and large culverts are, however, the trusted brick. There was still no reinforced concrete bridge carrying the weight of a train.

The next big project was the City Railway. John Bradfield very early on decided that the scheme would be a high level one with the tunnels and stations just below the surface. This necessitated the crossing of the low lying Belmore Park to be above ground on an embankment, thus requiring three bridges, over Eddy Avenue, Hay Street and Campbell Street. Bradfield's first conceptual design, included in his 1915 report completed after his return from his overseas study tour shows the three bridges as steel trusses. The drawing is a little fanciful as the bridges are narrow and insignificant. In reality, even in 1915, all three would have been four tracks wide and thus almost certainly made with at least three trusses. Eddy Avenue is shown as a single span, whereas it was always destined to be longer than that across the wide avenue.

A small amount of work was done on the new railway in 1916 and 1917 but then all work ceased until 1922. In the hiatus Bradfield revised the plans and the four tracks into the city became six, and in fact Eddy Avenue would be built as a seven track bridge. Four or five parallel sets of trusses with one or two tracks between each pair was not going to be acceptable so close to the magnificently elegant design of the near new Sydney Central station.

Bradfield went back to his favoured form of bridge structure – the arch. At least he intended to let the man and woman in the street who viewed this set of three bridges imagine that they were arches. His first problem was the flatness of the arches and the lack of road clearance. Eddy Avenue as it came east past the station rose

ABOVE: All of the City Railway structures, where there were public spaces below, were sealed by an asphalt layer, mechanically protected by a layer of brick. The complex shape of the multiple beams was no excuse to avoid this process. The farther ribs are black from the asphalt and the nearer ones are sheathed in bricks. A group of engineers, perhaps including Bradfield on the right, walks away. ARHSNSWRRC 517228

ABOVE: Erecting a steel falsework beam over the southern road lane. The centre set of girders had been erected first while two cranes had access over the central pier into the centre span. Note the reinforcing bars projecting from the centre wall. These will lock the whole structure, beams, piers, abutments and footpath spans as one rigid structure. ARHSNSWRRC 517315

BELOW: Under one of the road spans, one of which will always be retained open for traffic. The worker is a City Council employee performing a necessary task when much of the traffic was still horse drawn. The curved form is created by having the centre timber chocked above the steel beam, the next adjacent on the beam, the third housed into it and the fourth supported below the flange. ARHSNSWRRC 517316

BELOW: All of the beams are in place and carpenters are at work, forming the curved shape of the lower edge (soffit) of the concrete beams. They work above the trams, but the northern road span is closed. ARHSNSWRRC 517320

to Elizabeth Street and there was not anything that could be done to change that. The inbound[5] tramway bridge was a masonry arch, perhaps with an embedded steel truss formed of retired rails, but at that point the clearance was high enough. The outbound tramline was a steel bridge but as a single line it was highly decorative and quaint. Seven more of them together would not look so charming.

One means of easing the problem was to raise the level of the new electric platforms, and the tracks over the bridge, by four feet (1.2m).[6] This gave that much extra height below. Hay Street and Campbell Street bridges were acceptable as true arches, even if Campbell Street has restricted clearance at 3.8m. Both bridges are Monier arches, with significant amounts of reinforcing steel in the form of 'bars', and thus something of a construction landmark as they certainly carry the weight of trains. However, Eddy Avenue would still not work as an arch.

Bradfield, working with his design engineer Robert Boyd, turned to reinforced concrete, not to counter the effects of tension in a too-flat arch, but to create a beam bridge which would look like an arch and to the public eye be just a third identical member of a set of sandstone arches supporting the railway across the park. The design produced, which has claim to be the first reinforced concrete underbridge on the NSW Railways, is a clever and, after 90 years of constant use, an apparently sound one.

It has been suggested[7] that an earlier bridge over Bellevue Street in Glebe, on the Rozelle to Darling Harbour Line, built in 1919, predates Eddy Avenue. The plans of Bellevue Street show it as a set of closely spaced, large, steel "I" beams, encased in a slab of concrete. Assuming that this plan shows the bridge that was built, and is still in place under the Dulwich Hill light-rail line, it is not what any modern engineer would consider as 'reinforced concrete'. Bellevue Street spans a single road lane and is insignificant compared to Eddy Avenue, even if it might claim the title of 'first'.

A subway at Banksia, built at much the same time as Eddy Avenue is really an underbridge, but again its plans show it as a concrete encased set of steel joists.

There is one reinforced concrete bridge which could be identified as pre-dating Eddy Avenue, and it is only metres away from that street. The Northern Concourse of the new electric platforms is provided under the tracks, immediately adjacent to the platforms. The roof of that space is strong, to carry trains, and is unquestionably of reinforced concrete construction in the modern sense of the word. If the 'title' of first must be awarded then by what criterion is it to be assessed? Both bridges were built at the same time, though one must have been 'finished' before the other and both came into use at the same moment when the same train crossed both, seconds apart.

But the adoption of a reinforced concrete beam did not alone create the elegant solution which Bradfield sought. It would not look like an arch and with an apparently inescapably great depth near the centre of the spans, as simple beam bridges must have, the clearance problems remained. The answer was found by building a continuous bridge which relied for its spanning capacity as much on cantilever action from the support points as bending strength at mid span.

The wide avenue required a three span bridge over the traffic lanes and tram lines. The bridge could readily be made continuous by pouring the

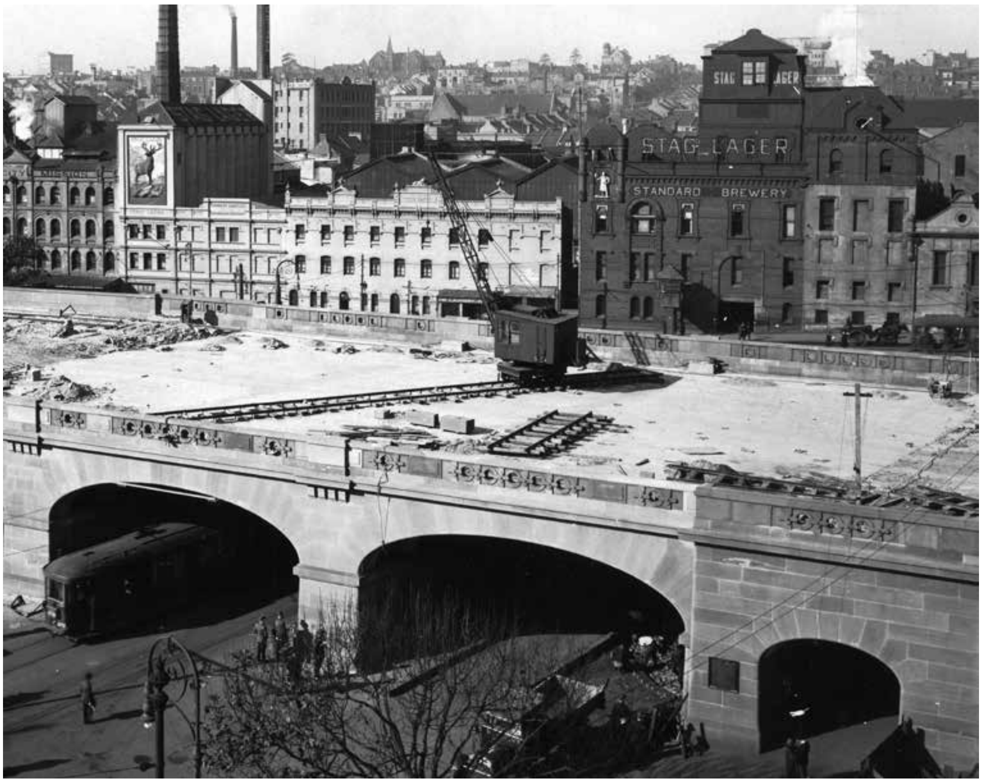
ABOVE LEFT: Upon the large timber baulks, which rest on the steel beams, shaped timber joists for the actual curved shape of the 'arch' are spaced. Because of the skew, these cannot reach from one end of the span to the other, so they stop and start part way across the road. On these joists are placed lagging and above these, timber walls will be built to form the trough into which the concrete will be placed. In the foreground reinforcing steel from the footpath spans projects into what will be the space for the final bridge girder. ARHSnswRRC 517322

ABOVE RIGHT: The typical arrangement for concreting in 1924. This is the northern abutment of the Hay Street Bridge. The mixer is placed high on a 'pig-sty' structure with a platform above, served by a crane, to stockpile metal, sand and cement. Concrete flows downhill, at first into the foundation which is 30 feet (9m) deep and then into the triangular skewback for the arch. ARHSnswRRC 517005

BELOW: Between the troughs for the girders formboards for the slab which reaches from beam to beam is set up. This work is not level as the final surface will drain to low points from which water is led away by pipes cast into the piers and abutments. ARHSnswRRC 517331

ABOVE: The immensity and complexity of the project is clear. Even if Bellevue Street was built to different plans and is a reinforced concrete bridge, it is a trifle compared to Eddy Avenue. ARHSnswRRC 517332

BELOW: At least two batching plants are in use. Only a narrow strip of the whole bridge will be concreted in a day as that is all the concrete that the plant can supply. ARHSnswRRC 517345



LEFT: The bridge is close to complete. The crane has lowered the large steel girders to the road, using holes in the deck. There were 14 of these electric cranes on the City Railway project and they moved all over the city for ten years. Apart from two steam navvies which did excavation, and a large Bucyrus drag line excavator which dug St James, they were the only large plant in use. ARHSnswRRC 517365

BELOW: Hay Street Bridge. Clearly one of a set of 'identical' elegant stone bridges between Central and the City. Readers with a sharp eye might note that the curve of the arch reaches the ground whereas at Eddy Avenue the curved span bears upon taller pillars, but the net result is an attractive solution to construction in a sensitive situation. ARHSnswRRC 517252

concrete for the three spans on the one day, with suitably placed steel reinforcing bars over the piers and abutments. The centre span would thus be supported by the outer spans and be very strong and rigid, but the outer spans would have nothing from which to cantilever, as beyond them there was nothing but the earth fill of the approach embankments. The answer to this need for rigid abutments was found in the short spans over the footpaths on both sides of the avenue. Although of only trivial span (12 feet, 3.6m) they are reinforced concrete girders as deep as the adjacent road spans. Further, the piers on either side of the footpath are wide and heavy and carry reinforcing bars up from the foundations into the beams of the bridges. They are designed as thoroughly rigid abutments, from which the road spans may well cantilever. With much of the strength of the bridge provided by the deep haunches, the central parts of each span are shallow and a satisfactory road clearance is obtained. Kerbs and footpaths keep traffic away from the low clearance portions near the support piers.[8]

So, the three bridges were designed to look like a set, though Eddy Avenue, structurally, is nothing like the other two. The next challenge was to build them. Campbell Street and Hay Street were simple enough projects, though like all civil engineering in 1923, intensively demanding of the

muscles of men and the design by the supervising engineers of every procedure in the erection. The two streets were closed for a time, falsework assembled, the concrete arch poured and the road re-opened. This option was not available at Eddy Avenue. The road was too busy to close and worse, it carried a vital tramline which could never be closed. The three span bridge could not be made one span at a time as the continuous design practically required all three to be poured simultaneously.

The cleverness of design and construction engineers in the 1920s came to the fore. The whole seven track wide by three span long bridge was formed up leaving all the road lanes and tramlines open except for brief times. In this citation of 'brief' the erection of the steel girders which form the heart of the falsework needs comment. The girders over the tramlines were erected first, early one Sunday morning, after the trams had ceased for the night. Timber trestles were already in place along each side of the central piers and two cranes, standing in the road lanes, lifted the girders from trucks. The total elapsed time was just 70 minutes and the tram wires were replaced and live. The girders were erected over the outside spans – the traffic lanes – using a single crane by closing the lanes for a few hours.[9]

As if the bridge design was not already sophisticated enough, there was now the issue that the road was skewed to the railway. The reinforced concrete beams, beneath the deck, followed

the railway alignment, whereas the falsework timber formers were square to the road. Thus these main timber constructions, which define the curve of the lower face of the beam, are truncated. They never reach from one side of the road to the other because they are always intersected by the skew of the railway. Soon enough however the careful planning allowed this complicated falsework and formwork to be placed and reinforcing bars, which are fundamentally no different to what would be used in a twenty first century construction, were placed. The girders and the deck were concreted across all three spans on the same day, though not across the full seven track width of the bridge as the capacity of the mixing plant and the delivery system could not supply that volume of concrete.

As with all City Railway concrete work, the material was batched on site, using electric mixers.[10] These machines were always carefully placed to allow, where possible, a downwards flow of the concrete to its place of use. At Eddy Avenue, where the bridge was flat and of large dimensions, wheelbarrows were used for distribution. The sandstone face, which presents the distant viewer with the appearance of a stone arch bridge, for the blocks are jointed as if they were voussoirs, is merely a façade, placed before the concrete and secured in place by that material flowing behind it.

Once the concrete had set and the requisite time for curing had been allowed, the next challenge was the dismantling of the falsework. Viewed from the street level, between each pair of deep ribs were large steel beams, which had supported the rest of the timber formwork. How were they to be got down? If Bradfield had had a high powered fork-lift he might have used it, but his plant was restricted to a fleet of rail-mounted electric cranes of limited reach and lifting capacity. He had planned for this part of the work, and had cleverly left small holes through the deck, above each girder. An electric crane, set up on the deck with its lift cable working through the hole, lowered each one in turn.

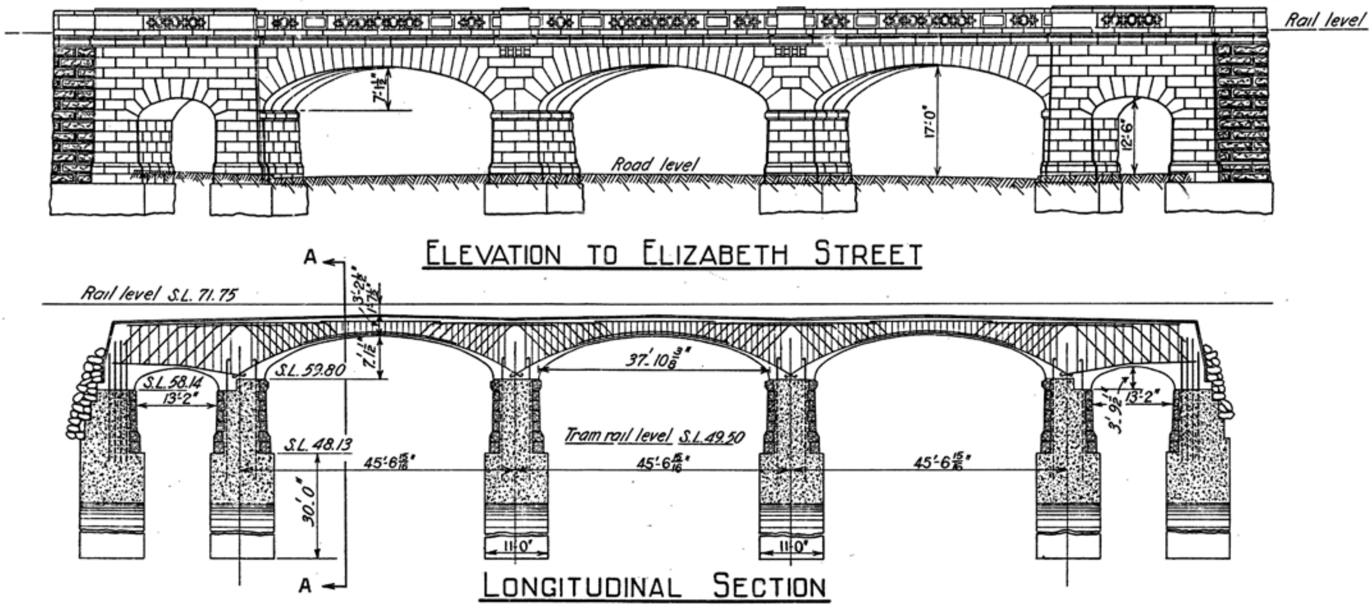
Further reinforced concrete underbridges were constructed in the following years, but none so sophisticated and elegant as Eddy Avenue. The bridge over the Southern and Western Ocean Outfall Sewer on the East Hills Line, between Wolli Creek Junction and Turrella, opened in 1931, has crude rectangular girders on either side of and between the double tracks. The O'Riordan Street Bridge on the Botany Line is of longer span and therefore greater dimension, but of the same simple, and unappealing, design.

Eventually pre-stressed concrete replaced reinforced concrete for railway bridges. The first was an overbridge on Sunny Holt Road at Blacktown in 1954. Pre-stressed concrete is not a fundamentally different concept to reinforced concrete, but rather a development from it to circumvent its limitations.

The author acknowledges that this essay arose directly out of the discovery by employees of Sydney Trains of a long missing album of photos and the subsequent loan of that volume to the Railway Resource Centre for scanning. It is amazing what can be gleaned from poring over high quality scans of excellent photographs.

ABOVE: The crudeness of the O'Riordan Street Bridge, on a goods railway in an industrial setting, emphasises the effort that was put into making Eddy Avenue so elegant in its location in the heart of a city, adjacent to a grand terminal station. ARHSnswRRC 023795A

BELOW: The elevation and section of Eddy Avenue Bridge. The depth of solid concrete - not fill - in the 'spandrels' and the large number of diagonal steel bars make it beyond question that this is a beam bridge and not an arch. Note also the massive back spans over the footpaths and the tie down bars cast into the solid concrete abutments and piers. The span of the road arches — 45'-6 15/16"- claims an amazing precision. RRC Collection



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Page 4 - William Rowan and his Steam Railcars

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Page 24 - The Eddy Avenue Underbridge

[1] The bridge was erected using falsework which included a space for the operating trains. Although the bridge is of double track span, the cutting over which it is placed has never been fully excavated.
[2] The RRC holds a copy of Monash's testimonial.
[3] Burwood is the next station to Strathfield and an adjacent local government body.
[4] *SMH* 19 October 1906 P3*; SMH* 7 July 1908 P9;
[5] The trams which used the arcade at Sydney Station originally travelled in the opposite direction through the arcade to the modern light rail to Dulwich Hill.
[6] Bradfield's 1926 paper "The City Railway" *IEAust Transactions*
[7] Don Fraser. Unpublished chronological list of various types of bridges. Copy held in the RRC.
[8] The northern span has no signposted height restriction, the centre span is restricted to 4.2m and the southern span has different heights shown for each end and mid-span.
[9] Bradfield describes this work in his 1926 IEAust paper.
[10] Some earlier phases of the work used steam powered mixers.